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The Absorption of Potassium and Phosphate Ions By Typical Soils of the Connecticut Valley

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THE ABSORPTION OF POTASSIUM AND PHOSPHATE IONS BY TYPICAL SOILS OF THE CONNECTICUT VALLEY

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Valley

It has been known for a long time that soils possessed the power of taking up or absorbing certain salts from a solution, and a large amount of work has confirmed the fact that soils show a selective power of absorption towords the different ions in the solution.(1) Thus in general the positive ion is absorbed to a greater extent than the negative, consequently leaving the soil solution in the acidic condition. This was formerly explained as a simple metathetical reaction,- the bases of the soil and of the solution interchanging, or as the hydrogen of the complex organic acids known as humic acids being replaced by the base of the salt in the solution. That there is more or less interchange among the bases is easily shown by analysis to be true, but it has been repeatedly proven that the base liberated by the soil is usually not nearly equivalent to the base absorbed from the solution.(2) Altho the acidity of the resulting soil solution may be explained by the former hypothesis as being due to the formation of an acid or an acid salt, yet it entirely fails to explain the latter fact of non equivalent metathesis.

Moreover, soil is not the only substance which shows the power of selective absorption. Cameron (3) has shown that metallic silver may be separated from a solution of silver nitrate by the selective absorption of charcoal; and moist cotton entirely free from soluble acid will redden blue litmus paper left in contact with it for some time. Linder and Picton (1) and also Whitney and Ober (2) have shown that when barium chlorid is used to precipitate arsenic trisulfid from colloidal solution, small amounts of barium are absorbed, leaving in the solution a corresponding amount of free hydrochloric acid. These phenomena may be explained by attributing to the substances enumerated a special selective absorbing power for the base in question, and Harris (3) points out that the action of soils in the presence of soluble salts may be explained in the same way. Harris further points out the probability of this explanation from the action of electrolytes in general on colloids, for Linder and Picton (4) have shown that the coagulation of negatively charged colloids is accompanied by the adsorption of the positively charged ion, and Coehn (5) has shown that the colloids of the soil will in general be charged negatively since their dielectric constant, being solids, is less than that of water.

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(1) Way:- J. Royal Agric. Soc. of Eng. (1850) 313-379.
Eichorn:- Landwirtschafliches Central-Blatt. (1858) II- 169.
Biedermann & Rautlenberg:- J. fur Landwirtschaft, New Series, (1862) VII- 49.
Armsby:- Am. J. of Science, (3) (1877) XIV- 75

(2) See references above.

(3) "The Soil Solution", p 66.

Thus the theory of selective absorption has been steadily gaining ground, and in 1906 Schreiner and Failyer (6) undertook a special study of several type soils with the intent of noting the effect of continued application of phosphate and potassium salt solutions, and subsequently of continued leaching, on the concentration of these salts in the soil solution. As a result they substantiated the theory developed by Schloessing, which is, in brief, that the concentration of soluble salts in the free soil moisture is largely dependent on the absorptive powers of the individual soils. The minerals of the soil yield, and apparently continue to yield a solution whose concentration approaches equilibrium between the solution and the solid, but as true equilibrium probably never exists there must be other factors entering in to effect this state, as the area of soil directly exposed to the soil moisture during a limited period of time would produce a disturbance in the equilibrium. But the concentration of salts in the soil solution tends to remain practically constant for any given soil. Thus for example if the concentration of potassium in the soil moisture should be lessened by the leaching of heavy rains, or the taking up of potassium by the plants, or by any other cause, this concentration would quickly be reestablished by the soil giving up of its absorbed potassium until the constant was again reached. Or if on the other hand the concentration of potassium in the soil solution should be increased, as by the application of a soluble fertilizer, or by evaporation of the soil moisture, the constanr would be restored by the absorption of the excess potassium by the soil.

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(1) J. Chem. Soc. LXVII - 63 - (1895)

(2) J. Chem. Soc. XXIII - 842 - (1901)

(3) J. Phys. Chem. XVIII - 355 - (1914)

(4) J. Chem. Soc. LXVII - 63 -(1895)

(5) Annalen der Physic und Chemie, Wiedemann, LXIV - 217 - (1898)

(6) Bur. of Soils, Bul. 32, (1906)

As the results of Schreiner and Failyer show a very marked difference between the absorptive capacities of the different type soils used in their experiments, and inasmuch as "type soils" are not definite compounds, that is, a soil described as a fine sand from Maryland might be quite different from and have very different absorptive capacities from a soil of the same description from Massachusetts, it was thot expedient to examine four of the most characteristic soils of the Connecticut Valley in order to determine their respective absorptive capacities for potassium and phosphate ions, and to plot the absorption and leaching curves for each type.

The soils studied in this investigation were a Windsor sand, a Podunk fine sandy loam, a Connecticut Meadow silt loam, and a Suffield clay.

The Windsor sand was obtained about a half mile north of Mount Orient on the Pelham Road. It is described (1) as consisting of six to ten inches of light yellow or brown course sand, resting on yellowish coarse sand and fine gravel, slightly loamy. Its origin is considered to be a shallow lake deposit. There are two types of this sand: a light loose form, and a heavier type which is more of a sandy loam. The former was the one studied.

The Podunk fine sandy loam was obtained about a mile west of the Massachusetts Agricultural College, and is described (2) as consisting of twelve inches of friable dark brown sandy loam, underlain with a yellow or brownish fine sandy loam. The material composing this soil originated by deposition in deeper lake waters, but has been largely reworked and redeposited by later stream action.

The Connecticut Meadow silt loam was obtained about a half mile west of North Amherst on Meadow Street, and is described (3) as consisting of a dark silt loam in the upper twelve inches. This is underlain by a heavier dark grayish to yellow or brown silt loam. The material consists of the finest grades of sand and silt that have been reworked and deposited by the streams along which it flows. In the process of reworking and deposition large amounts of organic matter have been incorporated with the sand and silt.

The Suffield clay was obtained about one and a half miles west of Amherst Centre on Amity Street. It is described (4) as consisting of four to eight inches of heavy dark drab clay loam resting on a heavy tenacious grey drab clay, which extends to a deapth of twenty and in some instances seventy-five feet. It is of deep lake origin, and while appearing very heavy and tenacious, it is laggely composed of silt, probably of the finer grades.

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(1) Soil Survey of the Connecticut Valley. Field Operations, Bur. of Soils, (1903)

(2) Same as above.

(3) Same as above.

(4) Same as above.

The apparatus used in these experiments was essentially that used in the laboratory of the Bureau of Soils on similar investigations.(1) The soil was placed within a nickel plated tube twelve inches long by one and a quarter inches inside diameter. A section of a Pasteur Chamberland filter was inserted at the lower end, the porus filter projecting about one and a half centimeters above the rubber stopper, which held it in position. The upper part of the filter was plugged with a solid rubber stopper, while the lower end was fitted with a one holed stopper with a glass tube thru which the solution percolated. The upper end of the nickel tube was fitted with a two holed stopper provided with two glass tubes. One of these was several feet in length, the length being determined by the pressure necessary to force the liquid thru the filter at the desired rate, i.e. 50 c.c. in 24 hours. This tube was connected by a syphon to a flakk containing the solution to be passed thru the filter. The shorter of the glass tubes was provided with a short piece of rubber tubing and a pinch cock, and served to let the air out of the tube when starting the experiment.

The samples of soil were weighed out, mixed with distilled water to form a thin paste and this poured into the nickel tube. The tube was then connected with the rest of the apparatus, the syphon started, and a small Erlenmeyer flask provided to catch the percolate. By lengthening or shortening the height of the water column, and by the use of screw pinch cocks on the rubber connections, the desired rate of flow was obtained.

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(1) Schreiner and Failyer: U.S. Bur. of Soils, Bul. 32, 11. (1906)

The apparatus is sketched below.

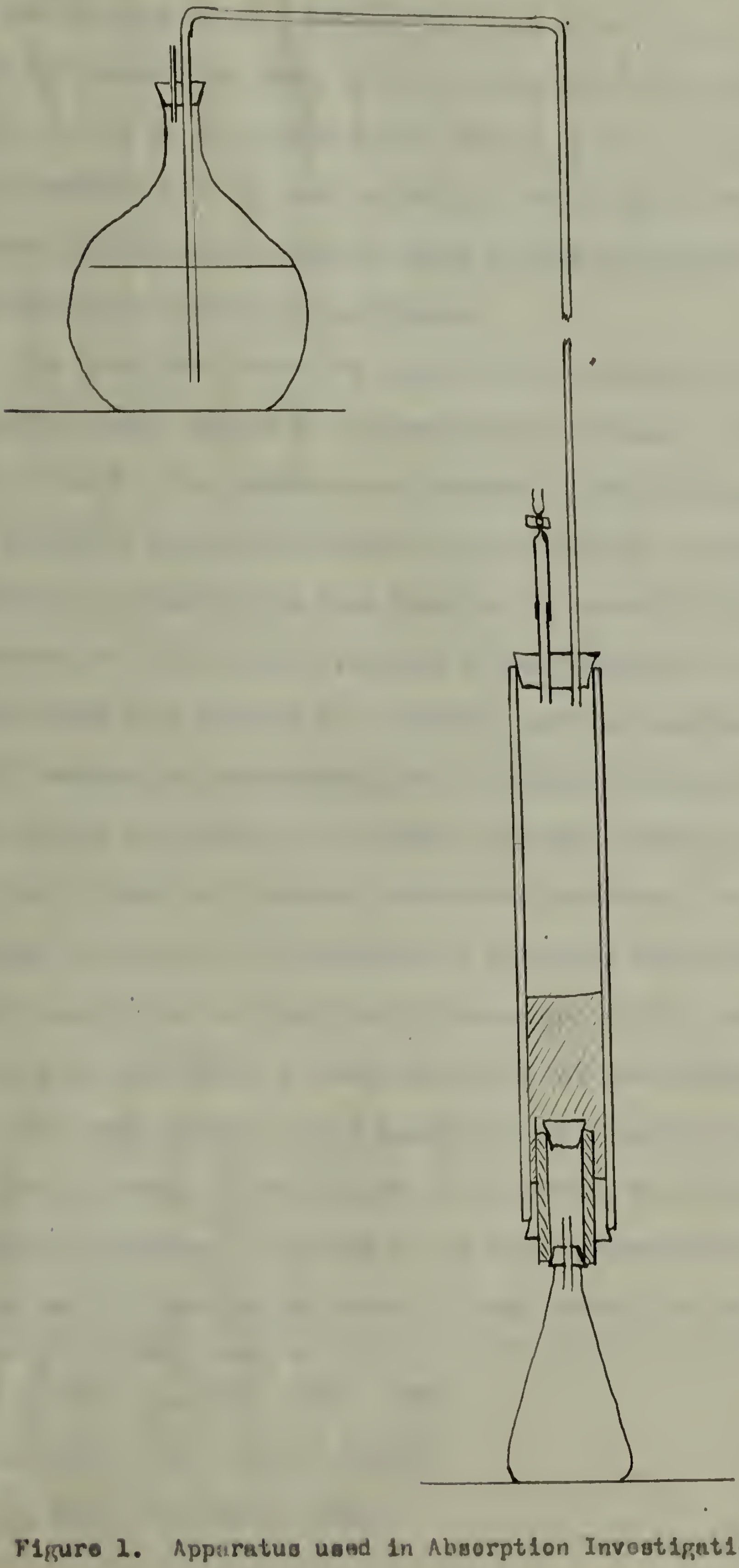

Figure 1. Apparatus used in Absorption Investigations.

Before a comprehensive study of the absorption of soluble salts by the soil can be made, it is necessary to know how the salt in question, which the soil already contains, will be affected by the continued leaching with water. And it is also necessary in order to make a just comparison of the absorption capacities of the various soils to have them all brot to a state of practical equilibrium, as regards their potassium and phosphate content, before begining the absorption experiments.

The tubes were therefore charged with 100 grams of the soil, and pure distilled water allowed to run thru them at the rate of 50 cubic centimeters in 24 hours. The percolate was collected in fractions, and the potassium and phosphate content determined in each fraction. The method used in the determination of potassium was that described by Cameron and Failyer (1), which is based on the red color produced by the addition of an excess of potassium iodide to a solution of a platinic salt, as described by Morrell.(2) "The method consists in precipitating the potassium as chlorplatinate, after removing ammonia by ignition, and washing this with alcohol in a manner similar to that followed in the usual gravimetric procedure. The chlorplatinate is dissolved in water, and the addition of potassium iodide developes the color above mentioned. The solution is then compared with a standard solution of potassium chlorplatinate in which the color has been similarly developed."

The method used in the determination of phosphate was that described by Schreiner and Brown (3) It consists in converting the phosphate into magnesium ammonium phosphate, as is done in the usual gravimetric procedure, all silica, as well as other salts, and to a large extent also, soluble organic matter, being removed by washing with ammonia water. The magnesium ammonium phosphate is dissolved in nitric acid and determined by means of the yellow color produced by the addition of ammonium molybdate, comparing with a standard phosphate solution in which the color is similarly developed. "

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(1) J. Am. Chem. Soc. XXV - 1063 (1903)

(2) J. Am. Chem. Soc. II - 145 (1880)

(3) J. Am. Chem. Soc. XXVI - (1904)

On testing out for the accuracy of these methods, a difference of three parts per million could usually be detected if the concentration in the sample was not greater than 200 parts per million. A higher concentration however, especially in the case of potassium, rendered the results somewhat less accurate.

The results for the removal of potassium from the soils are given in tables 1,2,3,&4. In the first column is given the number of cubic centimeters in each individual fraction of percolate analyzed. In the second is given the total number of cubic centimeters that have passed thru the filter. The third column shows the concentration of potassium in each of the fractions taken, expressed in parts per million of percolate. The fourth column expresses the amount of potassium extracted from the soil in each fraction, expressed in parts per million of soil, and the fifth column shows the total potassium extracted from the soil.

The figures of the fourth column were obtained by dividing the product of the first and third columns by 100, which formula was derived as follows: Let p.p.m. of potassium in any given fraction of solution be a, let the volume of percolate in the fraction be b, let p.p.m. of potassium extracted from the soil in the fraction be x, and let grams of potassium extracted from the soil in the fraction be y, then if there are a grams in 1,000,000 c.c., there will be y grams in b c.c., or a : 1,000,000 :: y : b or 1,000,000y = ab and y = $\frac{ab}{1,000,000}$. If $\frac{ab}{1,000,000}$ grams of potassium are extracted from 100 grams of soil, then x grams are ~~are~~ extracted from 1,000,000 grams of soil, or $\frac{ab}{1,000,000}$: 100 :: x : 1,000,000. Solving, x = $\frac{ab}{100}$.

Table 1.

Removal of Potassium from a Sandy Soil.

Volume of Sol. in sample	Total volume of solution	Potassium in Sample	Potassium in Sample	Total Potassium extracted
c.c.	c.c.	p.p.m.of sol.	p.p.m.of soil	p.p.m. of soil
55	55	10	5	5
45	100	7	3	8
86	186	6	5	13
86	272	6	5	18
119	391	3	4	22
129	520	4	5	27
134	654	4	5	32
186	840	3	6	38
166	1006	2	3	41
252	1258	3	8	49
332	1590	1	3	52
522	2112	2	10	62
1888	4000	1	18	80

Table 2.

Removal of potassium from a Sandy Loam.

Volume of Sol. in sample c.c.	Total volume of solution c.c.	Potassium in sample p.p.m.of sol.	Potassium in sample p.p.m.of soil	Total Potassium extracted p.p.m.of soil
50	50	28	14	14
54	104	20	11	25
108	212	16	17	42
78	290	17	13	55
127	417	12	15	70
111	528	9	10	80
142	670	8	11	91
220	890	6	13	104
240	1130	6	14	118
350	1480	4	14	132
854	2334	2	17	149
709	3043	4	28	177
957	4000	3	29	206

Table 3.

Removal of Potassium from a Silt Loam.

Volume of Sol. in sample c.c.	Total volume of solution c.c.	Potassium in sample p.p.m.of sol.	Potassium in sample p.p.m.of soil	Total Potassium extracted p.p.m.of soil
35	35	30	10	10
61	96	28	17	27
75	171	24	18	45
121	292	19	23	68
121	413	18	22	90
147	560	14	21	111
128	688	10	13	124
154	842	9	14	138
238	1080	4	9	147
167	1247	5	8	155
238	1485	4	9	164
1343	2828	3	40	204
1172	4000	4	47	251

Table 4.

Removal of Potassium from a Clay Soil.

Volume of Sol. in sample c.c.	Total volume of solution c.c.	Potassium in sample p.p.m.of sol.	Potassium in sample p.p.m.of soil	Total Potassium extracted p.p.m.of soil
48	48	20	10	10
67	115	17	11	21
116	231	14	16	37
124	355	14	17	54
93	448	9	8	62
139	587	6	8	70
98	685	7	7	77
114	799	4	5	82
164	963	4	7	89
215	1178	5	11	100
249	1427	3	7	107
1206	2633	4	48	155
1367	4000	3	40	195

It will be noticed that the percolate from the sandy soil is very quickly brot down to a concentration which is practically constant, while in each of the other cases much more of the distilled water has to pass thru before this constant is reached. The fact of there being a higher concentration of the potassium in the first few fractions is interesting. The assumption that this is due to readily soluble potash salts in the soil which are quickly leached out does not seem tenable in view of the absorptive powers of the soils as will be shown later. The probable explanation of this higher concentration at the start lies in the fact that the soils were air dried before the leaching process was begun, and it has been demonstrated by Whitney and Cameron (1) and later by King (2) that oven and air dried soils would yield a larger quantity of soluble salts to water than would the same soils in the moist condition.

The results for the removal of phosphates from the four soils are given in tables 5,6,7,and 8. The main noticable difference between the removal of the potassium and of the phosphate is that in the latter case the percolates from three of the four soils investigated increased somewhat in their phosphate content during the first part of the flow, whereas with the potassium the concentration in the percolate diminished regularly from the first. The same general tendency exists however as with the potassium, i.e. a fairly rapid diminution in the phosphate concentration to a certain point where it is maintained nearly constant.

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(1) Bur. of Soils, Bul. 22, 42, (1903)

(2) Bur. of Soils, Bul. 26, 55, (1905)

Table 5.

Removal of Phosphate from a Sandy Soil.

Volume of Sol. in sample c.c.	Total volume of solution c.c.	Phosphate in sample p.p.m.Sol.	Phosphate in sample p.p.m.of Soil	Total Phosphate extracted p.p.m.of Soil
52	52	12	6	6
50	102	10	5	11
55	157	9	5	16
54	211	8	4	20
82	293	7	6	26
104	397	5	5	31
116	513	5	6	37
115	628	4	5	42
113	741	4	4	46
119	860	5	6	52
138	998	4	5	57
117	1115	3	4	61
420	1535	4	17	78
607	2142	3	18	96
945	3087	2	19	115
913	4000	3	27	142

Table 6.

Removal of Phosphate from a Sandy Loam.

Volume of Sol. in sample c.c.	Total volume of solution c.c.	Phosphape in sample p.p.m.of Sol.	Phosphate in sample p.p.m.of Soil	Total Phosphate extracted p.p.m.of Soil
44	44	9	4	4
47	91	13	6	10
60	151	16	9	19
65	216	21	14	33
65	281	18	12	45
92	373	15	14	59
113	486	12	13	72
106	592	9	9	81
121	713	8	10	91
123	836	6	7	98
126	962	6	7	105
129	1091	6	8	113
392	1483	5	19	132
578	2061	5	29	161
1079	3140	4	43	204
860	4000	4	34	238

Table 7.

Removal of Phosphate from a Silt Loam.

Volume of Sol. in sample c.c.	Total volume of solution c.c.	Phosphate in sample p.p.m.of Sol.	Phosphate in sample p.p.m.of Soil	Total Phosphate extracted p.p.m.of Soil
56	56	15	8	8
51	107	17	9	17
44	151	18	8	25
49	200	16	8	33
74	274	14	10	43
81	355	11	9	52
103	458	10	10	62
111	569	8	9	71
113	682	7	8	79
101	783	6	6	85
121	904	4	5	90
164	1068	6	10	100
422	1490	5	21	121
477	1967	4	19	140
1035	3002	4	41	181
998	4000	4	40	221

Table 6.

Removal of Phosphate from a Clay Soil.

Volume of Sol. in sample c.c.	Total volume of solution c.c.	Phosphate in sample p.p.m.of Sol.	Phosphate in sample p.p.m.of Soil	Total Phosphate extracted p.p.m.of Soil
54	54	24	13	13
57	111	25	14	27
57	168	25	14	41
64	232	24	15	56
57	289	23	13	69
76	365	19	14	83
116	481	15	17	100
109	590	12	13	113
106	696	9	10	123
118	814	8	9	132
117	931	7	8	140
139	1070	6	8	148
443	1513	7	31	178
598	2111	6	36	214
1006	3117	6	60	274
883	4000	6	53	327

After prolonging the preliminary leaching until four liters of water had passed thru the soil, the tubes were allowed to drain completely, and these same soils were then treated in the same manner as before, one set with a solution of potassium chlorid, and the other set with a solution of monocalcium phosphate, $CaH_4(PO_4)_2$. These solutions were made up to a strength of 200 parts per million of potassium (K), and of phosphate (PO_4) respectively, and were prepared by diluting a stock solution which had previously been standardized by gravimetric analysis.

The results obtained on the absorption of potassium are given in tables 9,10,11, and 12. The first three columns are as in the leaching tables, i.e., 1st, the volume of percolate in the individual fraction; 2nd, the total volume of percolate which has passed thru the soil when any given fraction is taken; and 3rd, the concentration of potassium in the fraction of percolate taken. The fourth column represents the amount of potassium absorbed from the solution expressed in parts per million of solution, and is obtained by subtracting the concentration of the potassium in the solution, 3rd column, from 200, the concentration of the solution flowing thru. The fifth column represents the amount of potassium absorbed by the soil, expressed in parts per million of soil. This value was obtained by dividing the product of the potassium absorbed from the solution, 4th column, and the percolate in the fraction, 1st column, by 100, which formula was derived as previously shown. The last column shows the total amount of potassium absorbed, expressed in parts per million of soil, when any given fraction is taken.

Table 9.

Absorption of Potassium by a Sandy Soil.

Volume of Sol. in sample c.c.	Total vol. solution c.c.	Potassium in sample p.p.m. of Sol.	Potassium absorbed p.p.m. of Sol.	Potassium absorbed p.p.m. of Soil.	Total Potassium absorbed p.p.m. of Soil
43	43	3	197	85	85
46	89	14	186	86	171
38	127	26	174	66	237
64	191	78	122	78	315
106	297	151	49	52	367
117	414	179	21	24	391
116	530	188	12	14	405
92	622	192	8	7	412
95	717	193	7	7	419
89	806	190	10	9	428
101	907	194	6	6	434
86	993	193	7	6	440
94	1087	198	2	2	442
255	1342	197	3	8	450
296	1638	199	1	3	453
364	2002	198	2	7	460

Table 10

Absorption of Potassium by a Sandy Loam.

Volume of Sol. in sample c.c.	Total vol. solution c.c.	Potassium in sample p.p.m.of Sol.	Potassium absorbed p.p.m.of Sol.	Potassium absorbed p.p.m. Soil.	Total Potassium absorbed p.p.m.Soil
56	56	6	194	108	108
51	107	12	188	97	205
50	157	25	175	87	292
57	214	39	161	92	384
53	267	70	130	69	453
107	374	129	71	76	529
124	498	161	39	48	577
108	606	175	25	27	604
106	712	183	17	18	622
197	809	189	11	21	643
102	911	190	10	10	653
108	1019	195	5	5	658
105	1124	193	7	7	665
310	1434	198	2	6	671
287	1721	196	4	11	682
334	2055	198	2	6	688

Table 11

Absorption of Potassium by a Silt Loam

Volume of Sol. in sample c.c.	Total Vol. solution c.c.	Potassium in sample p.p.m.of Sol.	Potassium absorbed p.p.m.of Sol.	Potassium absorbed p.p.m.Soil	Total Potassium absorbed p.p.m.of Soil
51	51	4	196	100	100
53	104	10	190	100	200
44	148	18	182	80	280
63	211	29	171	108	388
59	270	44	156	92	480
98	368	69	131	128	608
119	487	107	93	111	719
106	593	150	50	53	772
113	706	164	36	41	813
109	815	179	21	23	836
123	938	187	13	16	852
117	1055	192	8	9	861
107	1162	195	5	5	866
288	1450	193	7	20	886
318	1768	195	5	16	902
292	2060	197	3	9	911

Table 12

Absorption of Potassium by Clay Soil

Volume of Sol. in sample c.c.	Total Vol. solution c.c.	Potassium in sample p.p.m. of Sol.	Potassium absorbed p.p.m. Sol.	Potassium absorbed p.p.m. Soil	Total Potassium absorbed p.p.m. of Soil
35	35	4	196	68	68
51	86	6	194	99	167
41	127	7	193	79	246
61	188	11	189	115	361
77	265	20	180	138	499
105	370	45	155	163	662
121	491	74	126	152	814
116	607	111	89	103	917
105	712	141	59	62	979
97	809	158	42	41	1020
107	916	172	28	30	1050
106	1022	184	16	17	1067
169	1191	187	13	23	1090
291	1482	191	9	26	1116
309	1791	193	7	28	1144
357	2148	191	9	32	1176

It will be seen that the concentration of potassium in the percolate increases very rapidly from the start, but however, with different degrees of rapidity for each soil, the percolates from the sandy soil increasing the most rapidly, the sandy loam next, the silt loam next, and the clay soil the slowest. This emphasizes two points: 1st, that the sandy soil reaches its state of saturation with respect to its potassium content in the shortest length of time, the clay soil taking the longest time to reach this condition; and 2nd, that the total absorptive capacity of the sandy soil is the lowest of the four soils, while that of the clay soil is the greatest, the clay soil absorbing 1176 parts of potassium as against 460 parts for the sandy soil, 688 parts for the sandy loam, and 911 parts for the silt loam., on the passage of nearly equal amounts of potassium chlorid solution.

The absorption of phosphates is shown in tables 13, 14, 15, and 16.

The most striking difference noted between these figures and those for the absorption of potassium is that the absorption of phosphate takes place very much slower. In fact the clay soil is still absorbing phosphate when nearly five liters of the solution have passed thru it, while in the case of the potassium, one liter was nearly sufficient to saturate the same soil. The same general relationship holds between the different soils with respect to the rate of absorption, and the total amount of phosphate absorbed, as with the potassium absorption.

Table 13

Absorption of Phosphate by a Sandy Soil.

Volume of Sol. in sample c.c.	Total vol. of solution c.c.	Phosphate in sample p.p.m. of Sol.	Phosphate absorbed p.p.m. Sol.	Phosphate absorbed p.p.m. Soil	Total Phosphate absorbed p.p.m. of Soil
56	56	8	192	107	107
48	104	15	185	89	196
59	163	22	178	105	301
65	228	41	159	103	404
108	336	80	120	130	534
135	471	105	95	128	662
117	588	132	68	80	742
104	692	133	67	70	812
133	825	170	30	40	852
112	937	168	32	36	888
115	1052	175	25	29	917
126	1178	181	19	24	941
117	1295	186	14	16	957
266	1561	194	6	16	973
323	1884	190	10	32	1005
283	2167	195	5	14	1019
1013	3180	197	3	30	1049
580	3760	196	4	23	1072
995	4755	198	2	20	1092

Table 14

Absorption of Phosphate by a Sandy Loam

Volume of Sol. in sample c.c.	Total vol. of solution c.c.	Phosphate in sample p.p.m. of Sol.	Phosphate absorbed p.p.m. Sol.	Phosphate absorbed p.p.m. Soil	Total Phosphate absorbed p.p.m. of Soil
47	47	5	195	92	92
53	100	5	195	103	195
56	156	11	189	106	301
73	229	16	184	134	435
69	298	19	181	125	560
119	417	32	168	200	760
114	531	45	155	177	937
127	658	55	145	184	1121
131	789	71	129	169	1290
102	891	88	112	114	1404
126	1017	100	100	126	1530
149	1166	121	79	118	1648
104	1270	135	65	67	1715
226	1496	148	52	117	1832
321	1817	163	35	112	1944
268	2085	172	28	75	2019
918	3003	186	14	128	2147
882	3885	190	10	88	2235
795	4680	192	8	71	2306

Table 15

Absorption of Phosphate by a Silt Loam

Volume of Sol. in sample c.c.	Total vol. of solution c.c.	Phosphate in sample p.p.m. of Sol.	Phosphate absorbed p.p.m. Sol.	Phosphate absorbed p.p.m. Soil	Total Phosphate absorbed p.p.m. Soil
57	57	4	196	112	112
47	104	4	196	92	204
58	162	7	193	114	318
55	218	10	190	106	424
110	328	15	185	203	627
127	455	21	179	227	854
119	566	40	160	176	1030
118	684	43	157	185	1215
114	798	60	140	160	1375
114	912	73	128	146	1521
120	1032	79	121	145	1666
132	1164	91	109	144	1810
123	1287	102	98	120	1930
204	1491	120	80	163	2093
276	1767	134	66	182	2275
279	2046	152	48	134	2409
1002	3048	175	25	250	2659
725	3800	181	19	143	2802
896	4696	186	14	125	2927

Table 16

Absorption of Phosphate by a Clay Soil

Volume of Sol. in sample c.c.	Total vol. of solution c.c.	Phosphate in sample p.p.m. of Sol.	Phosphate absorbed p.p.m. Sol.	Phosphate absorbed p.p.m. Soil	Total Phosphate absorbed p.p.m. Soil
45	45	6	194	87	87
56	101	5	195	109	196
57	158	6	194	110	306
50	208	7	193	96	402
101	309	11	189	191	593
108	417	17	183	208	801
117	534	20	180	211	1012
116	650	27	173	201	1213
121	771	40	160	193	1406
122	893	46	154	188	1594
123	1016	51	149	183	1777
134	1150	52	148	198	1975
122	1272	65	135	165	2140
111	1383	75	125	139	2279
324	1707	97	103	334	2613
339	2046	115	85	288	2901
948	2994	148	52	493	3394
810	3804	168	32	259	3653
905	4709	178	22	199	3852

It seems somewhat peculiar that in both cases the soils continue to absorb the ions in question, in very small amounts it is true, long after their approximate points of saturation have been reached, and in practically constant quantities for any given soil. It seems probable that this continued apparent absorption is due to a metathetical reaction between the potassium chlorid or the monocalcium phosphate and some of the mineral constituents of the soil, as for example: $NaAlSi_3O_8 + KCl = KAlSi_3O_8 + NaCl$, and $Ca_2Al_2Si_2O_8 + CaH_4(PO_4)_2 = H_4Al_2Si_2O_8 + Ca_3(PO_4)_2$. If this the case it seems probable that as the experiments were carried out this apparent absorption would continue indefinitely, or until all of the mineral matter of the soils that was capable of metathesis with the salts applied had undergone the reaction. Equilibrium could not be attained, inasmuch as the salt solutions entering are constantly percolating thru and being replaced by fresh solution. This theory was not, however, worked out in any detail, but offers interesting material for further investigation.

After continuing the absorption experiments for some time, the apparatus was again disconnected and allowed to thoroly drain as previously. Distilled water was then allowed once more to run thru the soils, at the same rate, and the rate and extent of the leaching out of the potassium and of the phosphate noted.

The results for the leaching out of the potassium from the four soils are given in tables 17, 18, 19, and 20. The columns are arranged as in the tables of the preliminary leaching.

Table 17

Removal of Absorbed Potassium from a Sandy Soil.

Volume of Sol. in sample c.c.	Total volume of solution c.c.	Potassium in sample p.p.m.of Sol.	Potassium in sample p.p.m.of soil	Total Potassium extracted p.p.m.of soil
46	46	58	27	27
52	98	24	12	39
53	151	11	6	45
63	214	12	8	53
56	270	8	4	57
45	315	8	4	61
67	382	4	3	64
88	470	5	4	68
95	565	6	6	74
123	688	5	6	80
182	870	4	8	88
185	1055	5	9	97
465	1520	4	18	115
488	2008	3	15	130

Table 18

Removal of Absorbed Potassium from a Sandy Loam

Vplume of Sol. in sample c.c.	Total volume of solution c.c.	Potassium in sample p.p.m.of Sol.	Potassium in sample p.p.m.of Soil	Total Potassium extracted p.p.m.of Soil
35	35	101	35	35
54	89	63	34	69
53	142	40	21	90
51	193	34	17	107
55	248	25	14	121
51	299	20	10	131
66	365	18	12	143
87	452	11	10	153
106	558	11	12	165
89	647	10	9	174
185	832	8	15	189
180	1012	9	16	205
465	1480	8	37	242
522	2002	8	42	284

Table 19

Removal of Absorbed Potassium from a Silt Loam

Volume of Sol. in sample c.c.	Total volume of solution c.c.	Potassium in sample p.p.m.of sol.	Potassium in sample p.p.m.of soil	Total Potassium extracted p.p.m.of soil
43	43	114	49	49
48	91	77	37	86
56	147	56	31	117
53	200	40	21	138
53	253	36	19	157
56	309	28	16	173
58	367	21	12	185
81	448	18	15	200
108	556	15	16	216
116	672	15	17	233
179	851	10	18	251
187	1038	11	21	272
408	1446	9	37	309
552	1998	9	50	359

Table 20

Removal of Absorbed Potassium from a Clay Soil

Volume of Sol. in sample c.c.	Total volume of solution c.c.	Potassium in sample p.p.m.of sol.	Potassium in sample p.p.m.of soil	Total potassium extracted p.p.m.of soil
51	51	137	70	70
41	92	103	42	112
46	138	90	41	153
53	191	63	33	186
61	252	57	35	221
63	315	42	26	247
71	386	38	27	274
80	466	28	22	296
112	578	25	29	325
106	684	21	22	347
188	872	19	36	383
188	1060	18	34	417
425	1485	14	60	477
545	2030	11	60	537

The leaching takes place very rapidly at first, diminishing in rate as more water passes thru, much the same as in the preliminary leaching. But it is at once noticed that the amount of potassium which is thus readily leached out is not nearly equivalent to the amount which had previously been absorbed by the same soil. By extended leaching the distilled water continues to take with it a small amount of potassium, but at a rate so slow that a very large amount of water would be required to extract all of the absorbed potassium from the soil. The only explanation for this seems to be that the potassium which has been absorbed has been converted into an insoluble compound which in turn goes back to the soluble form but very slowly. This appears to be in accordance with the explanation previously given to account for the continued absorption of the potassium and phosphate ions from the solution after the approximate point of saturation had been reached. The soil appears to be able to "take up" mineral salts in solution in two ways: 1st, by absorption, as we commonly understand the term, wherein the soil merely saturates itself, like a sponge, with the salts, these being readily soluble, and as easily washed out as taken up; and 2nd, by metathesis, wherein the mineral constituents of the soil interact with the salts in the solution producing insoluble compounds which are reconverted into the soluble salts just as slowly as the soluble salts were first transformed into insoluble compounds, and are thus not readily washed out.

The results for the leaching of the phosphate are expressed in tables 21, 22, 23, and 24.

Table 21

Removal of Absorbed Phosphate from a Sandy Soil

Volume of Sol. in sample c.c.	Total volume of solution c.c.	Phosphate in sample p.p.m.of sol.	Phosphate in sample p.p.m.of soil	Total Phosphate extracted p.p.m.of soil
52	52	185	96	96
78	130	151	118	214
76	206	118	90	304
109	315	89	97	401
97	412	68	66	467
138	550	48	66	533
146	696	35	51	584
183	879	24	44	628
125	1004	20	25	653
236	1240	12	28	681
337	1577	9	30	711
171	1748	8	14	725
264	2012	8	21	746
604	2616	6	36	782
608	3224	3	18	800
784	4008	7	55	855
702	4710	6	42	897

Table 22

Removal of Absorbed Phosphate from a Sandy Loam

Volume of sol. in sample c.c.	Total volume of solution c.c.	Phosphate in sample p.p.m.of sol.	Phosphate in sample p.p.m.of soil	Total phosphate extracted p.p.m.of soil
48	48	180	66	66
59	107	161	95	181
96	203	139	133	314
108	311	117	126	440
97	408	95	92	532
108	516	81	87	619
155	671	66	102	721
179	850	51	91	812
144	994	39	56	868
228	1222	31	71	939
326	1548	19	62	1001
203	1751	12	24	1025
251	2002	11	28	1053
638	2640	8	51	1104
605	3245	8	48	1152
667	3912	6	40	1192
809	4721	7	57	1249

Table 23

Removal of Absorbed Phosphate from a Silt loam

Volume of Sol. in sample c.c.	Total volume of solution c.c.	Phosphate in sample p.p.m. of sol.	Phosphate in sample p.p.m. of soil	Total phosphate extracted p.p.m. of soil
57	57	178	101	101
60	117	159	95	196
92	209	146	134	330
100	309	128	128	458
114	423	110	125	583
121	544	99	120	703
131	675	83	109	812
178	853	72	128	940
174	1027	63	110	1050
234	1261	47	110	1160
271	1532	32	87	1247
194	1726	28	54	1301
263	1989	18	47	1348
518	2507	15	78	1426
632	3139	16	114	1540
662	3791	10	66	1606
937	4728	9	84	1690

Table 24

Removal of Absorbed Phosphate from A Clay Soil

Volume of sol. in sample c.c.	Total volume of solution c.c.	Phosphate in sample p.p.m.of sol.	Phosphate in sample p.p.m.of soil	Total phosphate extracted p.p.m.of soil
51	51	174	89	89
61	112	166	101	190
104	216	153	159	349
89	305	146	130	479
106	411	134	142	621
127	538	125	159	780
124	662	112	139	919
186	848	100	186	1105
185	1033	87	161	1266
210	1243	74	155	1421
285	1528	63	180	1601
233	1761	49	114	1715
309	2070	41	127	1842
519	2589	26	135	1977
603	3192	21	127	2104
708	3900	16	113	2217
878	4778	15	132	2349

Here the phosphate is leached out, as in the case of the potassium, quickly at first, but becoming less and less rapid as the process continues. The main difference to be noted, however, is the much slower rate with which this is accomplished, the soils requiring about five times as much water to bring the phosphate content down to a constant. This large amount of water corresponds closely to the amount of solution required to bring the phosphate content up to a constant, during the absorption process. The total amount of phosphate extracted when this constant is finally reached is, however, far short of the amount of phosphate previously absorbed, as was the case with the potassium.

These results may be expressed graphically, and in this form show, perhaps, to better advantage the similarities and differences which exist for the various soils, and under the different forms of treatment.

In figure 2 are shown the solution curves for the preliminary leaching out of the potassium from the four soils under examination. The abscissas represent the liters of distilled water which have passed thru the 100 grams of soil in the percolating tubes, and the ordinates show the concentration of potassium, expressed in parts per million, of the resulting solution. The curves are all smoothed curves.

In figure 3 are shown the soil curves for the preliminary leaching. That is, the ordinates, instead of representing the concentration of potassium in the solution, indicate the amount of potassium which has been extracted from the soil, expressed in parts per million of soil. The abscissas, as before, represent the liters of water that have passed thru the soils.

Potassium - Preliminery Leaching Solution Curves

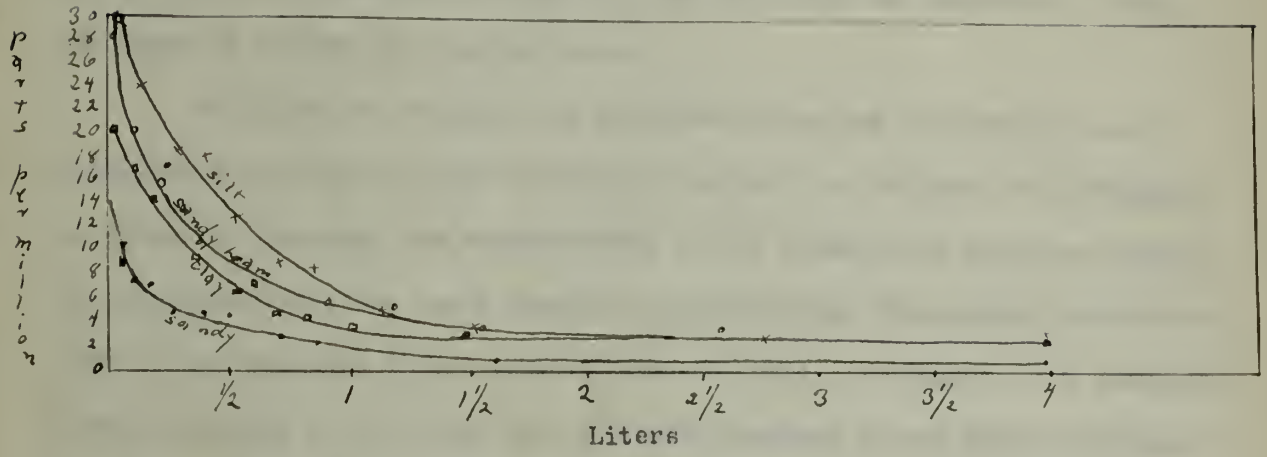

Figure 2. Showing parts per million of potassium in solution on passing distilled water thru the untreated soils. Data in tables 1,2,3,&4

Potassium - Preliminare leaching - Soil Curves

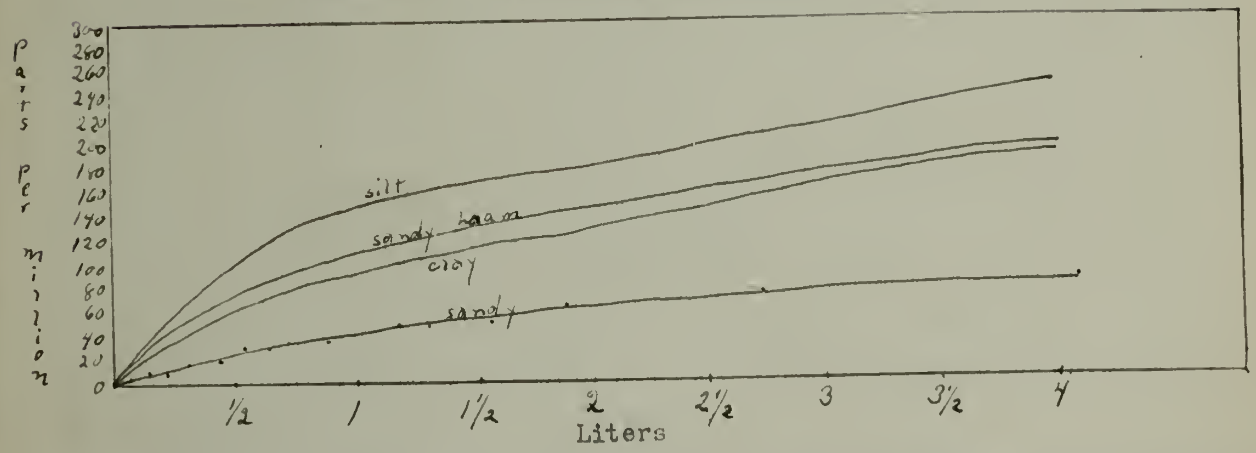

Figure 3. Showing parts per million of potassium extracted from the soils on passing distilled water thru the soils.

Data in tables 1,2,3,and 4.

These figures show very clearly that after about one and a half liters of water have passed thru the soils the concentration of potassium in the percolate is practically constant, and also that the soils are losing potassium at a slow but constant rate.

In figure 4 are shown the solution curves for the absorption of potassium ions, and in figure 5 the soil curves for the same. The ordinates in figure 4 represent the concentration of the solution in parts per million of potassium ions, the upper boundary line indicating the original concentration of the solution before passing thru the soil. In figure 5 the ordinates show the amount of potassium that has been absorbed by the soils, expressed in parts per million of soil. The abscissas in both cases represent the liters of solution that have passed thru.

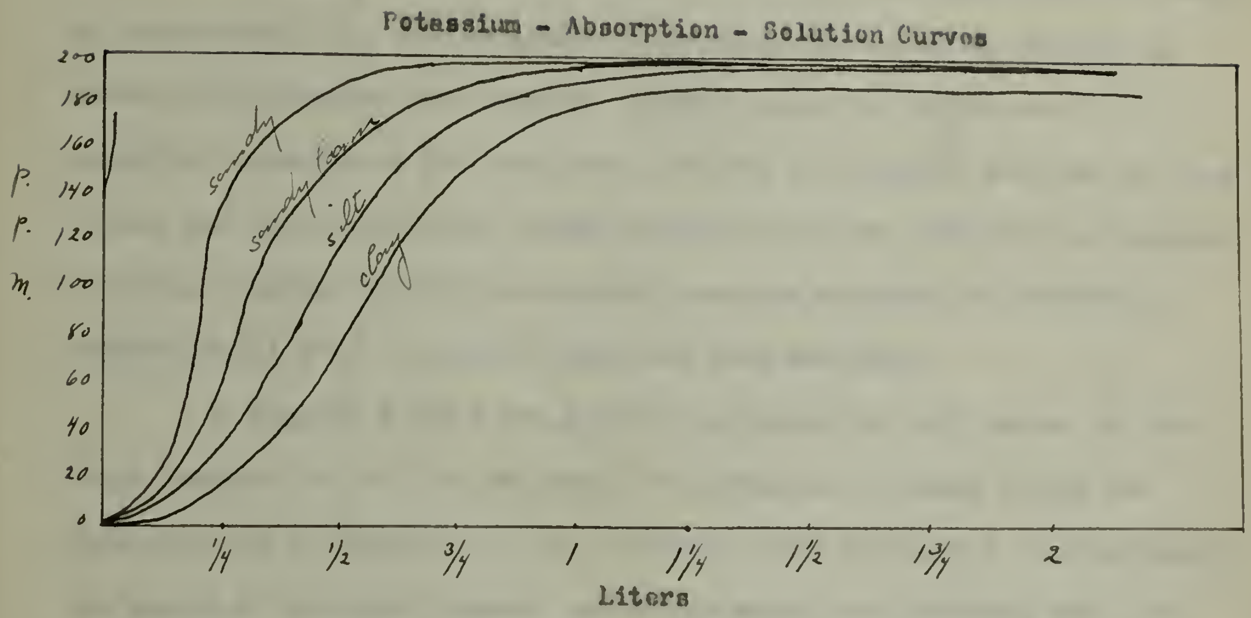

Figure 4. Showing parts per million of potassium in solution on passing potassium chlorid solution thru the soils.

Data in tables 9,10,11,and 12.

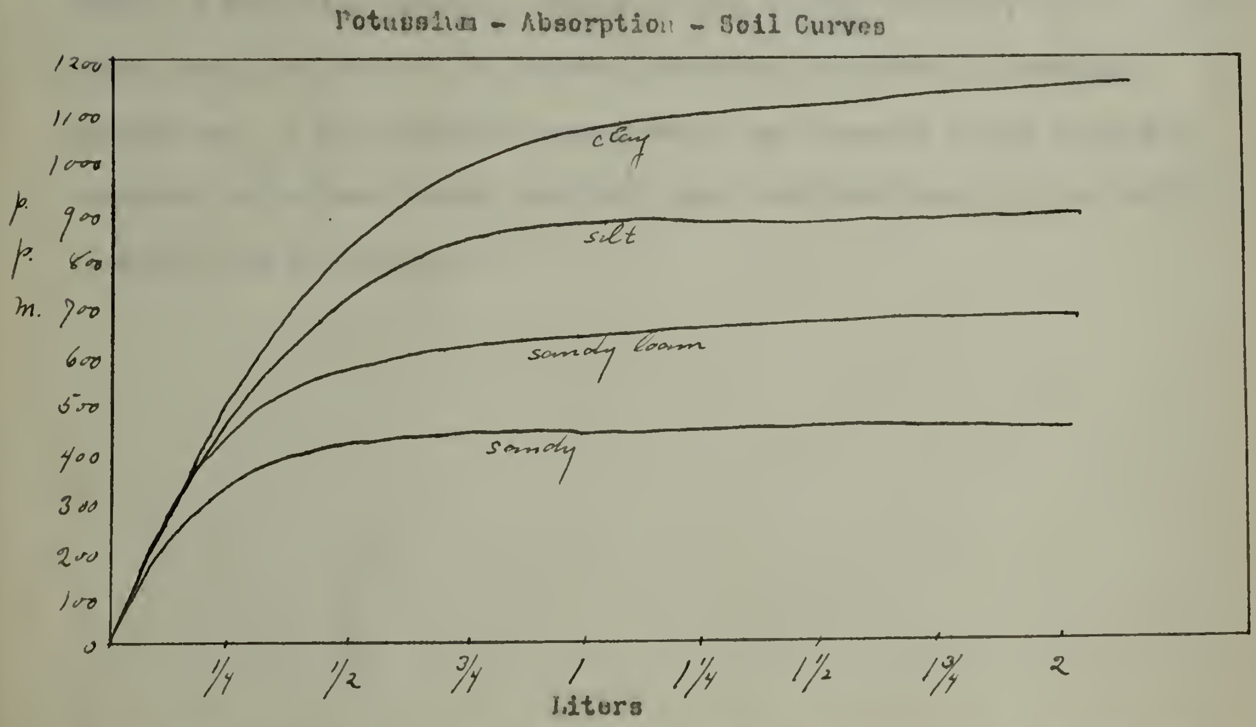

Figure 5. Showing parts per million of potassium absorbed by the soils on passing potassium chlorid solution thru them.

Data in tables 9,10,11,and 12.

Here again, after about a liter of solution has passed thru the soils the concentration in the percolates is constant and the soils continue to absorbe the potassium at a slow but constant rate. The differences in the absorptive capacity of the four soils are also very clearly brot out by these curves, the sandy soil being nearly saturated when only 400 parts per million have been absorbed, while the clay soil does not approach the horizontal position until over a thousand parts have been absorbed.

In figures 6 and 7 are given the solution and soil curves for the final leaching out of the potassium. The ordinates in figure 6 show the concentration of potassium in the solution, while in figure 7 they represent the amount of potassium leached out of the soils. The abscissas show the liters of water which have passed thru.

Instead of starting the leaching curves at the point represented by the end of the absorption curves, i.e. from a point representing the total amount of potassium absorbed, they have been started uniformly from the same point, zero, the rise in the curves indicating the amount of potassium leached out. A more accurate comparison of the behavior of the different saturated soils when treated similarly with distilled water, may be made by plotting them in this manner.

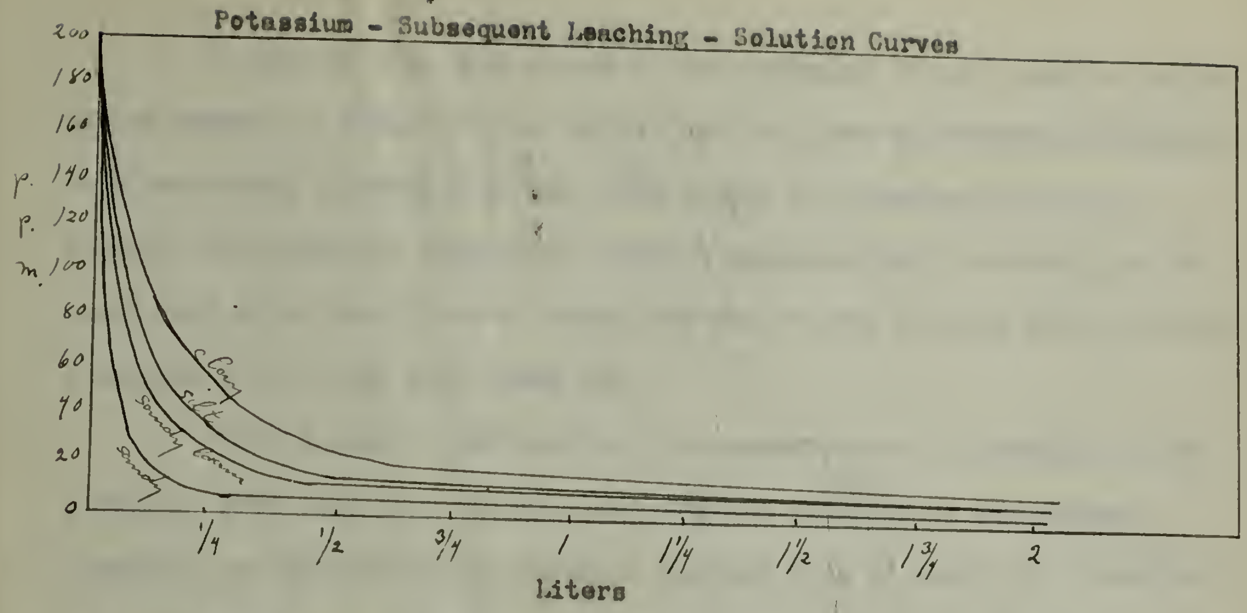

Figure 6. Showing parts per million of potassium in solution on passing distilled water thru soils which have been treated with potassium chlorid solution. Data in tables 17,18,19, and 20.

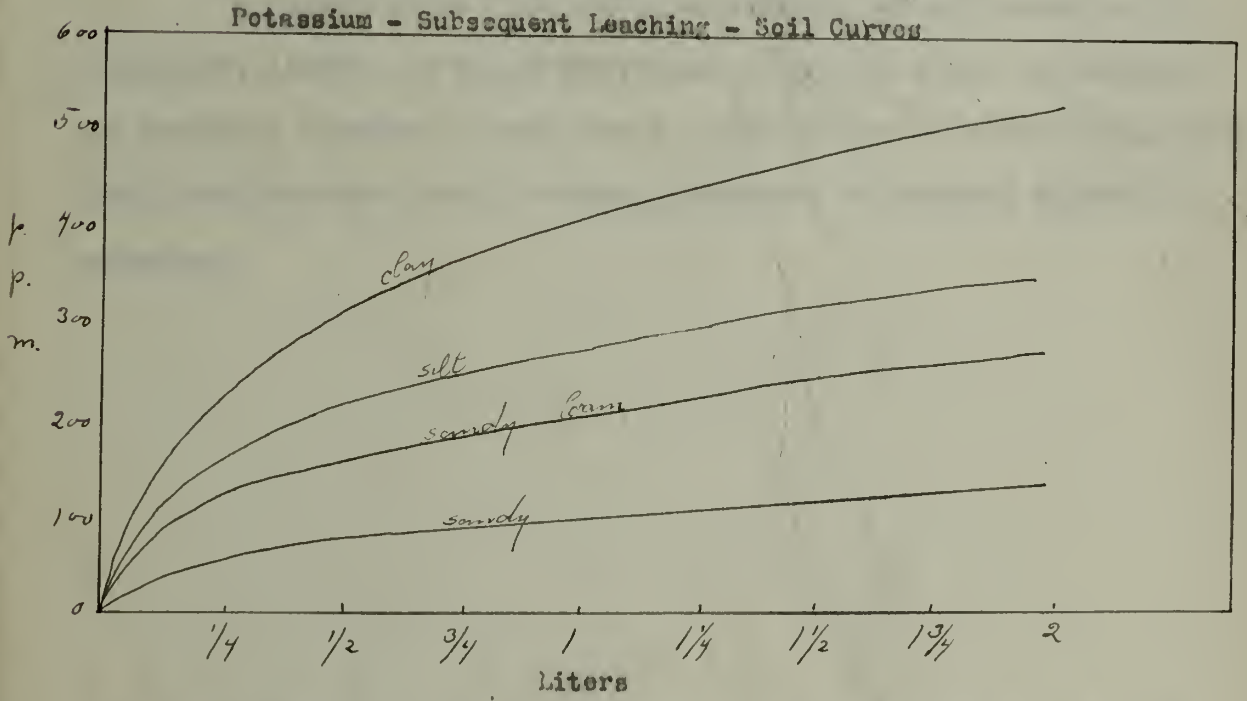

Figure 7. Showing parts per million of potassium extracted from soils which have been treated with potassium chlorid solution, on passing distilled water thru them. Data in tables 17,18,19, and 20

It will be seen that a part of the potassium is very quickly removed on the passage of water thru the soils, but that even by continued treatment with water only a fraction of the total amount of potassium absorbed is removed, the parts per million of absorbed potassium still remaining in the sandy soil after two liters of water have passed thru it being 330, and that remaining in the clay soil being 639.

It will also be noticed that the concentration of potassium in the percolate gets down very close to the constant attained in the original leaching, and that the soils attain a constant rate of loss, with reference to their potassium content, which is practically the same as the rate of loss in the original leaching. But the important point is that the soils still retain a large percentage of the potassium absorbed by them, even after these constants are reached.

In figures 8 and 9 are shown the solution and soil curves for the preliminary leaching of the ~~of the~~ phosphate from the soils. The abscissas and ordinates represent in each case the same factors as in the corresponding plots with potassium, only, of course, phosphate is indicated instead of potassium.

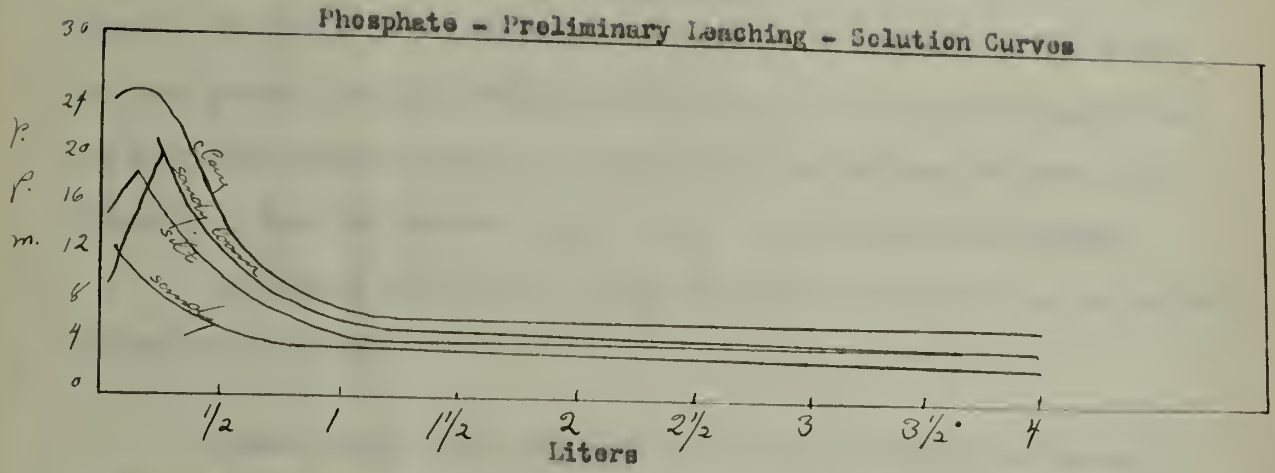
Phosphate - Preliminary Leaching - Solution Curves

Figure 8. Showing parts per million of phosphate in solution on passing distilled water thru the untreated soils.

Data in tables 5,6,7,and 8.

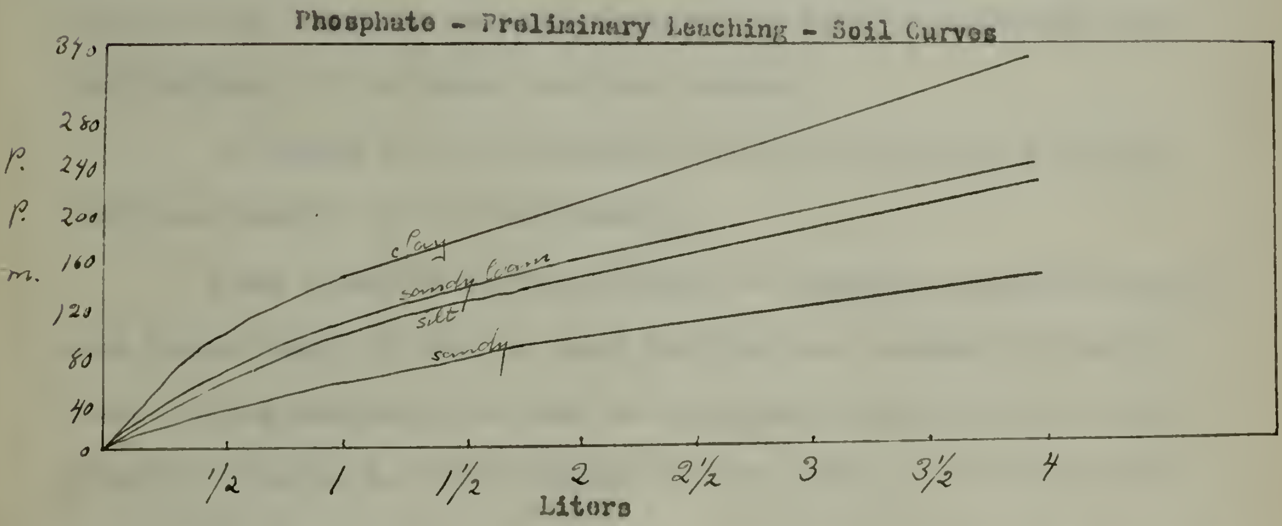
Phosphate - Preliminary Leaching - Soil Curves

Figure 9. Showing parts per million of phosphate extracted from the soils on passing distilled water thru the untreated soils.

Data in tables 5,6,7,and 8.

The peculiar rise in phosphate concentration of the solutions from three of the soils is an apparent unconformity with the rest of the curve. The same general tendency exists, however, as in the potassium experiments, the percolate quickly falling to a constant concentration, and the soils attaining a slow but constant rate of loss in their phosphate content.

In figures 10 and 11 are shown the solution and soil curves for the absorption of phosphate.

These curves differ markedly from the corresponding curves for potassium in the rate with which the soils become saturated, and also in the total amount absorbed. Here the clay soil is still rapidly absorbing phosphate when nearly five liters of solution have passed thru it, while the same soil has reached its constant with respect to potassium when only about one liter has passed thru. And when two liters of phosphate solution have passed thru the clay soil it has absorbed 2800 parts of phosphate, while when an equal amount of potassium solution has passed thru the same soil, only 1150 parts of potassium have been absorbed.

In figures 12 ams 13 are shown the solution and soil curves for the final leaching out of the phosphate.

Here, again, as in the absorption of phosphate, the soils require a much larger amount of water to bring them down to a constant than was the case with the potassium. But like the potassium, only a part of the total phosphate absorbed has been removed when this constant is finally reached.

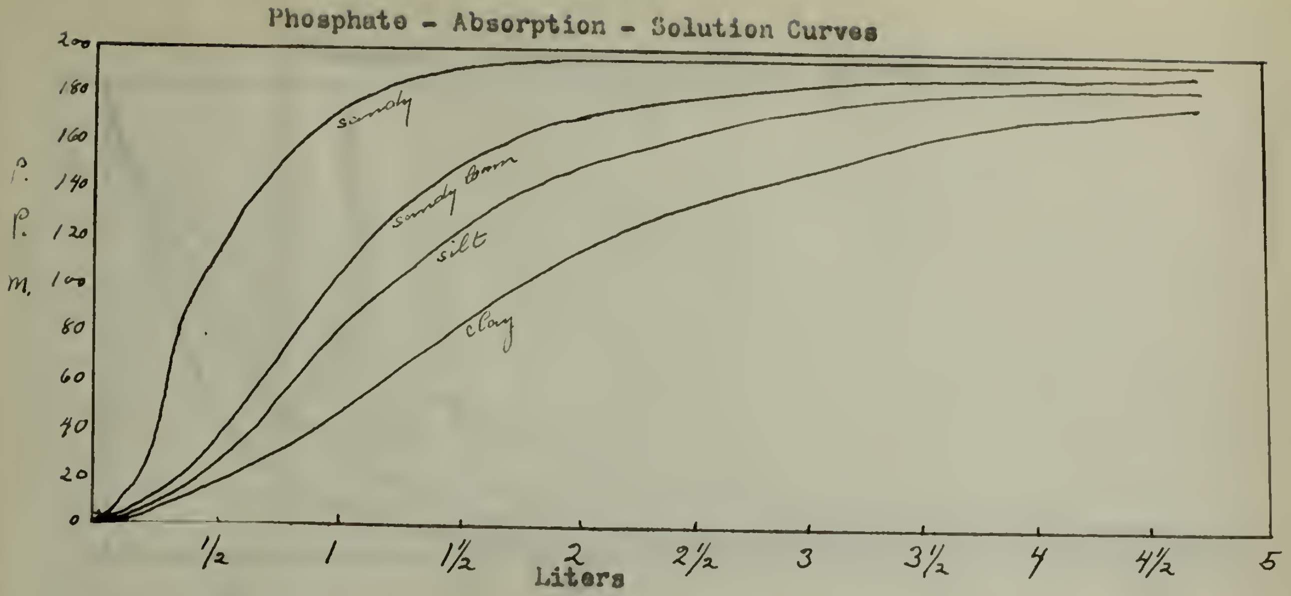

Figure 10. Showing parts per million of phosphate in solution on passing monocalcium phosphate solution thru the soils.

Data in tables 13,14,15, and 16.

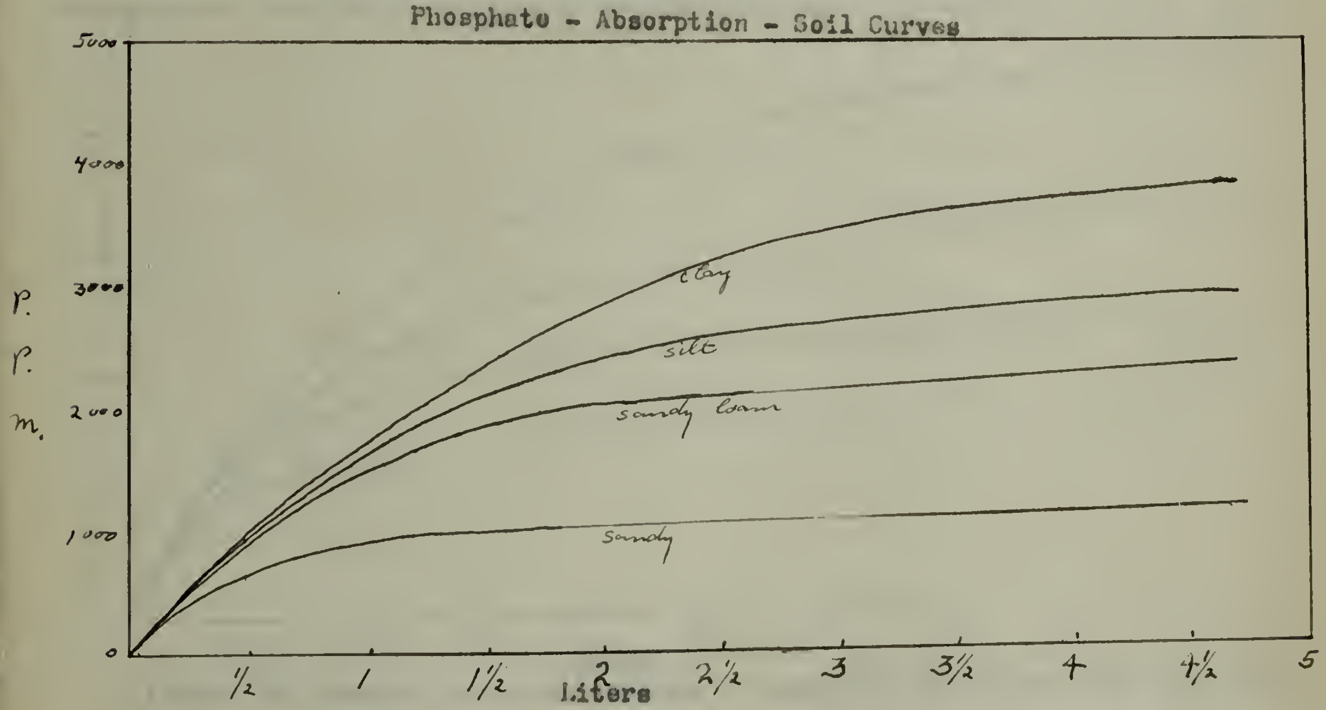

Figure 11. Showing parts per million of phosphate absorbed by the soils on passing monocalcium phosphate solution thru them.

Data in tables 13,14,15, and 16.

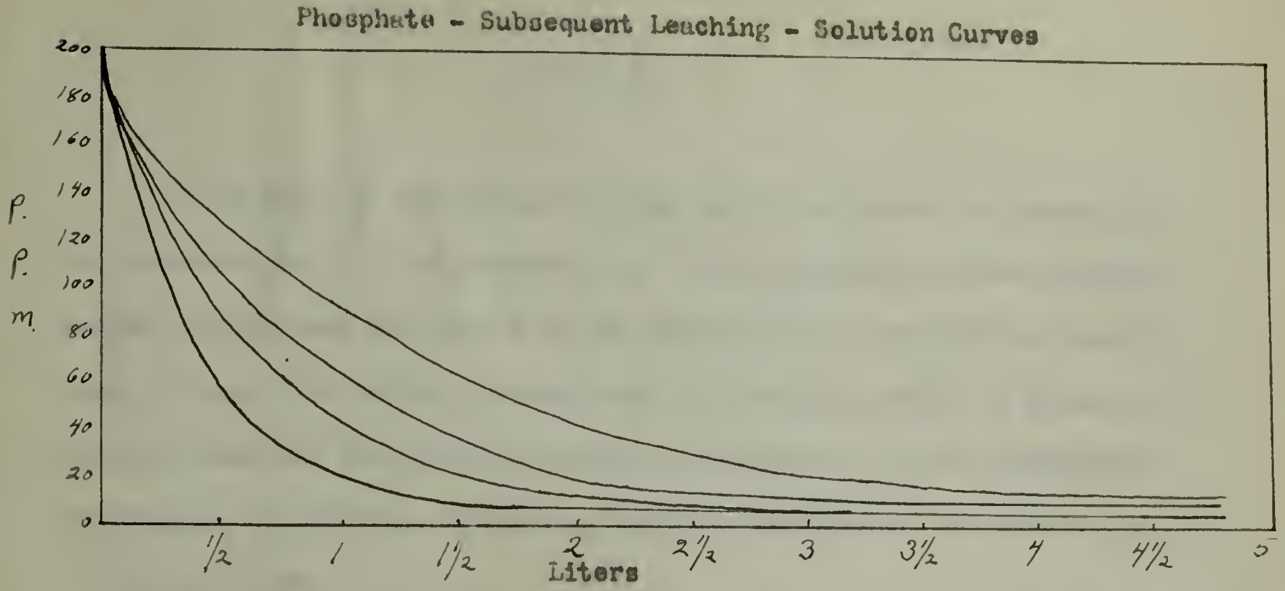
Phosphate - Subsequent Leaching - Solution Curves

Figure 12. Showing parts per million of phosphate in solution on passing distilled water thru the soils which have been treated with monocalcium phosphate solution. Data in tables 21,22,23,and 24.

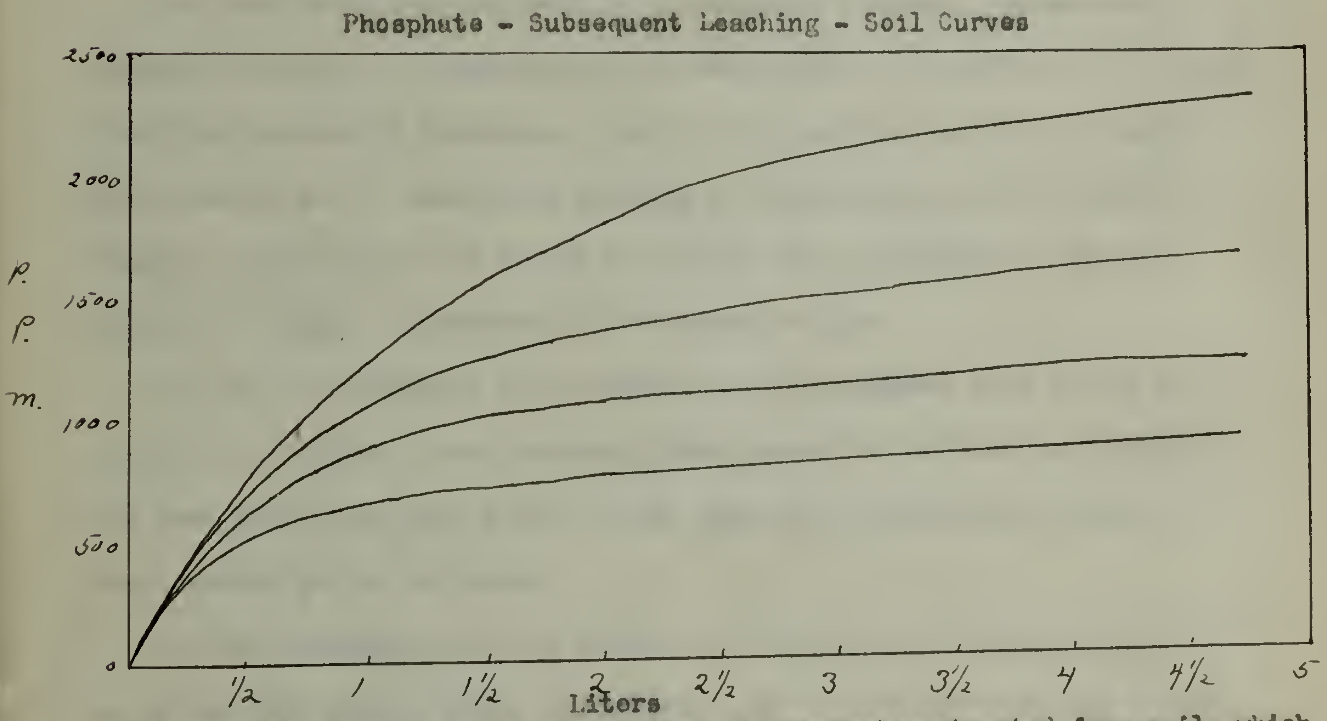
Phosphate - Subsequent Leaching - Soil Curves

Figure 13. Showing parts per million of phosphate extracted from soils which have been treated with monocalcium phosphate solution, on passing distilled water thru them. Data in tables 21,22,23, and 24.

- SUMMARY -

The study of these four Connecticut Valley soils has accomplished two purposes: 1st, it has presented the data, summarized in the foregoing curves, of the rate and extent of the absorption of potassium and phosphate ions by these four soils, together with the rate and extent to which these absorbed ions are subsequently leached out; and 2nd, it has substantiated the results of Cameron, Schreiner, Failyer, Schloessing, and others, in the following points:

1 - When soils are subjected to the leaching action of water, the concentration of potassium and phosphate ions in the soil extract approaches a constant, which appears to be fixed and definite for any given soil.

2 - When soils are subjected to the action of soluble potassium and phosphate salts, the concentration of these salts in the soil extract is at first not materially increased, owing to the power of the soils to absorb these salts, but as absorption procedes it becomes weaker, and a point is finally reached where the amount of soluble salts extracted in the soil extract is nearly equivalent to the amount applied.

3 - The concentration of the potassium and phosphate ions in the soil extract approaches a low constant, which appears to be fixed and definite for each soil, when only a part of the absorbed ions have been removed by the leaching action of water.

4 - The constants attained by the four soils by the leaching action of water are very nearly alike, which would seem to indicate that the concentration of the potassium and phosphate ions in the soil solutions of the various soils were practically the same, and not at all dependent on the

amount of absorbed potassium or phosphate they originally contained.

5 - These results substantiate the theory that the concentration of salts in the soil solution is very largely dependent on the specific absorptive capacity of the individual soil.

6 - These results, furthermore, tend to disprove the theory that the composition of the soil moisture , hence the absorptive capacity of the soil, is determined primarily by the chemical composition of the soil, but tend rather to prove this quality to be dependent on the mechanical texture of the individual soil.

Furthermore, inasmuch as these soils continue to absorb small amounts of potassium and phosphate ions long after the approximate point of saturation has been reached; and as these soils continue to lose these potassium and phosphate ions in small amounts long after the soluble forms must have been entirely leached out; and as this latter point is reached long before all of the previously absorbed potassium and phosphate ions have been leached out, it would appear that the soils were able to take up these ions from the solution in two distinct ways: 1st, by saturating itself with the ions, these undergoing no chemical change, and thus remaining readily soluble, and easily leached out; and 2nd, by interacting with the salts, producing insoluble compounds which are reconverted into soluble forms on the application of water but very slowly. Thus on the application of a salt in solution the soil first rapidly absorbs the various ions for which it has an attraction, and in proportion to the strength of this attraction, and then procedes slowly to interact with the salts to produce insoluble compounds. On the application of water to this soil, the soluble absorbed salts would be quickly leached out, and then the insoluble compounds would in turn be very slowly rendered soluble, by the reversion of the previous reactions, and ultiamtely they, too, would pass off in the solution.

Acknowkedgement is due Dr. Ernest Anderson for suggesting this investigation, and to Dr. Anderson and Professor Morse for advice and further suggestions before its completion.